

# UTILITY PATENT APPLICATION TRANSMITTAL

## (Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.  
XA-9387

Total Pages in this Submission

### TO THE ASSISTANT COMMISSIONER FOR PATENTS

Box Patent Application  
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

**ABERRATION MEASURING APPARATUS, ABERRATION MEASURING METHOD, PROJECTION EXPOSURE APPARATUS HAVING THE SAME MEASURING APPARATUS, DEVICE MEASURING METHOD USING THE SAME MEASURING METHOD, AND EXPOSURE METHOD**

and invented by:

Hitoshi TAKEUCHI



If a **CONTINUATION APPLICATION**, check appropriate box and supply the requisite information:

☒ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No. PCT/JP99/02608

Which is a:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.:

Which is a:

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Enclosed are:

### Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 62 pages and including the following:
  - a. ☒ Descriptive Title of the Invention
  - b. ☒ Cross References to Related Applications (if applicable)
  - c. ☐ Statement Regarding Federally-sponsored Research/Development (if applicable)
  - d. ☐ Reference to Microfiche Appendix (if applicable)
  - e. ☒ Background of the Invention
  - f. ☒ Brief Summary of the Invention
  - g. ☒ Brief Description of the Drawings (if drawings filed)
  - h. ☒ Detailed Description
  - i. ☒ Claim(s) as Classified Below
  - j. ☒ Abstract of the Disclosure

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## Application Elements (Continued)

3. ☒ Drawing(s) (when necessary as prescribed by 35 USC 113)
- a. ☒ Formal Number of Sheets 9
- b. ☐ Informal Number of Sheets \_\_\_\_\_
4. ☒ Oath or Declaration
- a. ☒ Newly executed (original or copy) ☐ Unexecuted
- b. ☐ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional application only)
- c. ☒ With Power of Attorney ☐ Without Power of Attorney
- d. ☐ DELETION OF INVENTOR(S)  
Signed statement attached deleting inventor(s) named in the prior application,  
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
5. ☐ Incorporation By Reference (usable if Box 4b is checked)  
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. ☐ Computer Program in Microfiche (Appendix)
7. ☐ Nucleotide and/or Amino Acid Sequence Submission (if applicable, all must be included)
- a. ☐ Paper Copy
- b. ☐ Computer Readable Copy (identical to computer copy)
- c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

## Accompanying Application Parts

8. ☒ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(B) Statement (when there is an assignee)
10. ☐ English Translation Document (if applicable)
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS Citations
12. ☐ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☐ Certificate of Mailing
- ☐ First Class ☐ Express Mail (Specify Label No.): \_\_\_\_\_

**UTILITY PATENT APPLICATION TRANSMITTAL**  
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Docket No.

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Total Pages in this Submission

**Accompanying Application Parts (Continued)**

15. ☒ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*  
Japanese Application No. 10-153915 filed May 19, 1998
16. ☐ Additional Enclosures *(please identify below)*:

**Request That Application Not Be Published Pursuant To 35 U.S.C. 122(b)(2)**

17. ☐ Pursuant to 35 U.S.C. 122(b)(2), Applicant hereby requests that this patent application not be published pursuant to 35 U.S.C. 122(b)(1). Applicant hereby certifies that the invention disclosed in this application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication of applications 18 months after filing of the application.

**Warning**

***An applicant who makes a request not to publish, but who subsequently files in a foreign country or under a multilateral international agreement specified in 35 U.S.C. 122(b)(2)(B)(i), must notify the Director of such filing not later than 45 days after the date of the filing of such foreign or international application. A failure of the applicant to provide such notice within the prescribed period shall result in the application being regarded as abandoned, unless it is shown to the satisfaction of the Director that the delay in submitting the notice was unintentional.***

# UTILITY PATENT APPLICATION TRANSMITTAL (Large Entity)

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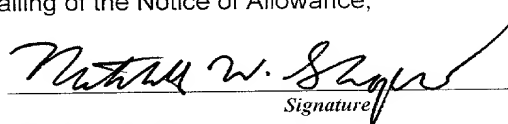
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## Fee Calculation and Transmittal

### CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	35	- 20 =	15	x \$18.00	\$270.00
Indep. Claims	9	- 3 =	6	x \$80.00	\$480.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0 00
BASIC FEE					\$710.00
OTHER FEE (specify purpose) Assignment Recordation Fee					\$40.00
TOTAL FILING FEE					\$1,500.00

- ☒ A check in the amount of \$1,500.00 to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. 22-0585 as described below. A duplicate copy of this sheet is enclosed.
- ☐ Charge the amount of as filing fee.
- ☒ Credit any overpayment.
- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).

  
Signature

Reg. No. 31,568

Dated: November 17, 2000

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NF06030PCTUS

ABERRATION MEASURING APPARATUS, ABERRATION MEASURING  
METHOD, PROJECTION EXPOSURE APPARATUS HAVING THE SAME  
MEASURING APPARATUS, DEVICE MANUFACTURING METHOD USING  
5 THE SAME MEASURING METHOD, AND EXPOSURE METHOD

This application claims the benefit of International  
application No. PCT/JP99/02608 and Japanese Patent  
application No. 10-153915 which are hereby incorporated  
10 by reference.

#### BACK GROUND OF THE INVENTION

##### Field of the Invention

The present invention relates to a wavefront  
aberration measuring apparatus for measuring a wavefront  
15 aberration and an optical performance of a measurement  
target optical system, especially projection optical  
system provided in a projection exposure apparatus, etc.  
used when manufacturing a measurement target optical  
system, especially a semiconductor device or a liquid  
20 crystal display device, and to an aberration measuring  
method. The present invention relates also to a  
projection exposure apparatus having the same measuring  
apparatus, and a device manufacturing method using the  
same measuring method. It is to be noted that the present  
25 application is based on Japanese Patent Application  
No.10-153915 of which the contents are hereby  
incorporated by reference.

### Related Background Art

There has hitherto been a method of using an interference optical system in the case of measuring a wavefront aberration of a measurement target optical system. According to the method based on the interference optical system, the wavefront aberration is measured by incorporating the measurement target optical system defined as a measurement target into the interference optical system, and the Twyman-Green interferometer and the Fizeau interferometer are known. For example, the Twyman-Green interferometer is constructed such that the light beam from a laser light source is divided into two fluxes of light (beam) by a half-mirror, one flux of light transmit the measurement target optical system, and the other flux of light is set as reference light beam. Then, the light beam transmitting the measurement target optical system interferes with the reference light beam, and an aberration of the measurement target optical system is measured from interference fringes thereof.

Further, what is known as a method of measuring a wavefront of the light beam from the measurement target optical system is a method called the Shack-Hartmann method using a lens array (Parity vol.05, No.10, 1990-10, pp.37 ~ 39). A wavefront measurement based on this Shack-Hartmann method is that a fluctuation of the wavefront from the celestial body is measured. As shown

in FIG. 9, to begin with, a wavefront (which will hereinafter be termed a [measurement target wavefront]) transmitting a measurement target optical system TL (indicating herein a telescope) is converted into  
5 parallel light beam by a collimator lens CL. Then, the parallel light beam is incident on a lens array (which will hereinafter be called a [two-dimensional lens array] where minute lenses L' are two-dimensionally arrayed. Herein, if the measurement target wavefront has a  
10 deviation from an ideal wavefront, this deviation appears to be a positional deviation of a converging position of the measurement target wavefront from a converging position of the ideal wavefront on a converging position detection unit DET. The wavefront is thereby measured  
15 based on the positional deviation of the converging position of each individual lens of the two-dimensional lens array.

There arise, however, the following problems inherent in the prior art described above. The  
20 interferometer method needs an interference optical system device used only for measuring the wavefront aberration. This interference optical system device is easy to be influenced by vibrations because of measuring the interference on the order of wavelength, and  
25 therefore requires an anti-vibration board. Therefore, this leads to a scale-up of the device, resulting in a problem of causing a decline of a using efficiency.

A main purpose of the wavefront measurement based on the Shack-Hartmann method is, as mentioned above, originally to measure the fluctuation of the wavefront from the celestial body, and therefore the Shack-Hartmann method is incapable of measuring the wavefront aberration of the lens used in the projection exposure apparatus for manufacturing a semiconductor device, etc..

In the wavefront measurement based on the Shack-Hartmann method, the two-dimensional lens array is used with a high precision, however, if there exists a scatter in terms of an accuracy of each lens of the lens array, an accuracy of detecting the converging position also declines. Hence, there might be a possibility in which the wavefront cannot be measured with the high precision.

#### SUMMARY OF THE INVENTION

It is a primary object of the present invention, which was devised to obviate the above problems, to provide an aberration measuring apparatus that is small in size, easy to manufacture and capable of readily measuring a wavefront aberration with a high accuracy, an aberration measuring method, a projection exposure apparatus including the same measuring apparatus, a device manufacturing method using the same measuring method, and an exposure method.

To accomplish the above object, according to the



invention of aspect 1, an aberration measuring apparatus comprises a converging lens (L) for converging light beam traveling through a measurement target optical system (PL) on a predetermined surface (IP), an aperture stop (AP) for transmitting a part of the light beam, a moving unit (M) for moving the aperture stop within the flux of light (light beam), a converging position detection unit (DET) for detecting a positional deviation of a converging position (P) of a part of the light beam traveling through the aperture stop on the predetermined surface, and an arithmetic processing unit (PC) for calculating an aberration of the measurement target optical system on the basis of an output signal from the converging position detection unit.

According to the invention of aspect 2, the converging lens converges a part of the light beams, and the moving unit moves the converging lens integrally with the aperture stop in the direction intersecting the optical axis of the light beam.

According to the invention of aspect 3, an aberration measuring apparatus for measuring an aberration of a projection optical system (PL) for transferring onto, a substrate (WH), an image of a predetermined circuit pattern formed on a mask (R), comprises an aberration measuring optical system (PH) for emitting a light for measuring the aberration fall upon the projection optical system, a plurality of lens

elements (L'), two-dimensionally arrayed, for converging the light beam for measuring the aberration which travel through the projection optical system, a converging position detection unit (DET) for detecting each of positions of the light beam converged by the plurality of lens elements, and a measuring device (PC) for measuring the aberration of the projection optical system on the basis of the converged light beam positions detected by the converging position detection unit.

Herein, the aberration measuring optical system may embrace pinholes of a reticle or a stage, or a transmission member for transmitting the light beam in diffusion, which will be mentioned later on.

According to the invention of aspect 4, the aberration measuring optical system may include a mask (R) for measuring the aberration, disposed substantially in the same position as the mask formed with the predetermined circuit pattern is disposed and having a pinhole pattern, and an illumination optical system (1 to 10) for illuminating the mask for measuring the aberration with the light beam.

According to the invention of aspect 5, the illumination optical system may be an illumination optical system (1 to 10) for illuminating the predetermined circuit pattern with the light beam.

According to the invention of aspect 6, an aberration measuring method comprises a step for

converging light beams traveling through a measurement target optical system (PL) on a predetermined surface by the use of a converging lens (L), a step for making an aperture stop transmit a part of the light beam;

5           a moving step for moving the aperture stop (AP) with the flux of light a converging position detecting step for detecting a positional deviation of each of a converging position (P) of a part of the light beam traveling through the aperture stop on the predetermined  
10           surface by the use of a converging position detection unit (DET), and an arithmetic processing step for calculating an aberration of the measurement target optical system on the basis of an output signal obtained in the converging position detecting step.

15           According to the invention of aspect 7, a part of the light beam is converged in the converging step, and the converging lens is moved integrally with the aperture stop in the direction intersecting the optical axis of the light beam in the moving step.

20           According to the invention of aspect 8, an aberration measuring method of measuring an aberration of a projection optical system (PL) for forming, on a substrate (WH), an image of a predetermined circuit pattern formed on a mask (R), comprises a step for  
25           converging the light beams for measuring the aberration that have passed through the projection optical system by the use of a plurality of lens elements (L'), two-

dimensionally arrayed a step for detecting each of positions of the light beams converged by the plurality of lens elements, and a step for measuring the aberration of the projection optical system on the basis of the detected light beam positions.

According to the invention of aspect 9, the light beam for measuring the aberration is light beam from a pinhole pattern (PH) on a mask, for measuring the aberration, disposed substantially in the same position as the mask is disposed.

According to the invention of aspect 10, a projection exposure apparatus comprises an illumination optical system (1 to 10) for illuminating a predetermined circuit pattern with the light beam, a projection optical system (PL) for forming the circuit pattern illuminated with the light beam on a substrate (WH), and an aberration measuring apparatus, of aspect 1, for measuring an aberration of the projection optical system.

According to the invention of aspect 11, a projection exposure apparatus comprises an illumination optical system (1 to 10) for illuminating a mask (R) having a predetermined circuit pattern with the light beam, a stage (11) for supporting the mask, a projection optical system (PL) for forming on the substrate an image of the circuit pattern illuminated with the light beam, and an aberration measuring apparatus, of aspect 1, for

measuring an aberration of the projection optical system. The stage or the mask has a generation member (PH) for generating light beam for measuring the aberration of the projection optical system.

5           According to the invention of aspect 12, the generation member is a pinhole pattern (PH) for converting the light beam from the illumination optical system into spherical waves.

10           According to the invention of aspect 13, the generation member may be a transmission member for transmitting in diffusion the light beam from the illumination optical system.

15           According to the invention of aspect 14, a projection exposure apparatus having a projection optical system (PL) for transferring onto a substrate (WH) an image of a circuit pattern formed in a mask (R), comprises an aberration measuring optical system (PH) for emitting a light beam for measuring the aberration upon the projection optical system, a lens array (L') for  
20           converging the light beams for measuring the aberration which travel through the projection optical system, and a converging position detection unit (DET) for detecting each of positions of the light beams converged by the lens array.

25           According to the invention of aspect 15, the aberration measuring optical system may include a mask (R) for measuring the aberration, disposed substantially

in the same position as the mask formed with the predetermined circuit pattern is disposed and having a pinhole pattern (PH), and an illumination optical system (1 to 10) for illuminating the mask for measuring the aberration with the light.

According to the invention of aspect 16, the projection exposure apparatus may further comprise a control unit (LC) for controlling a position of at least one of optical members constituting the projection optical system on the basis of a detected result given from the converging position detection unit.

According to the invention of aspect 17, the projection exposure apparatus may further comprise a substrate stage (13) for holding the substrate. At least the lens array or the converging position detection unit may be detachably provided on the substrate stage.

According to the invention of aspect 18, a device manufacturing method including a step for transferring an image of a predetermined circuit pattern onto a substrate (WH) by the use of a projection optical system (PL), comprises a step for measuring an aberration of the projection optical system by the use of the aberration measuring method of aspect 6.

According to the invention of aspect 19, a device manufacturing method including a step for transferring an image of a predetermined circuit pattern onto a substrate by the use of a projection optical system (PL),

comprises a step for measuring an aberration of the projection optical system by the use of the aberration measuring method of aspect 8.

According to the invention of aspect 20, an exposure  
5 method comprises a step for exposing a substrate to the light beam of a predetermined circuit pattern in a way of projecting the circuit pattern on the substrate by the use of the projection exposure apparatus of aspect 11.

According to the invention of aspect 21, an exposure  
10 method for transferring onto a substrate (WH) an image of a predetermined circuit pattern by the use of a projection optical system (PL), comprises a step for making light beam for measuring an aberration incident upon the projection optical system before transferring  
15 the circuit pattern onto the substrate, a step for converging the light beam for measuring the aberration that have passed through the projection optical system by the use of a plurality of lens elements (L') two-dimensionally arrayed, a step for detecting each of  
20 positions of the light beams converged by the plurality of lens elements, a step of measuring the aberration of the projection optical system on the basis of the detected positions of the light beams, and a step for correcting the aberration of the projection optical system on the  
25 basis of the measured aberration.

According to the invention of aspect 22, the aberration may be a wavefront aberration of the

projection optical system.

According to the invention of aspect 23, an exposure apparatus having a projection optical system (PL) for transferring onto a substrate (WH) an image of a pattern formed on a mask (R), said apparatus comprises: and a  
5 holding mechanism for detachably holding the aberration measuring apparatus of aspect.

According to the invention of aspect 24, the holding mechanism may include a first holding member (11) for  
10 holding an aberration measuring optical system, and a second holding member (12, 13) for holding a measuring unit (UT') having a plurality of lens elements, a converging position detection unit and a measuring device.

According to the invention of aspect 25, the first  
15 holding member may be a mask stage (11) for holding the mask, and the second holding member is a substrate stage (13) for holding the substrate.

According to the invention of aspect 26, the  
20 aberration measuring optical system may be a mask (R) for measurement, formed with a pinhole pattern (PH) for measuring the aberration.

According to the invention of aspect 27, an  
25 aberration measuring apparatus for measuring an aberration of a projection optical system (PL) for transferring onto a substrate (WH) an image of a pattern formed on a mask (R), comprises a measuring unit (UT')



detachably provided on an exposure apparatus including a mask stage (11) for holding the mask, the projection optical system, and a substrate stage (13) for holding the substrate. The measuring unit may include a

5 plurality of lens elements (L'), two-dimensionally arrayed, for converging light beam for measuring an aberration that have passed through the projection optical system, a converging position detection unit (DET) for detecting each of positions of the light beams

10 converged by the plurality of lens elements, and a measuring device (PC) for measuring the aberration of the projection optical system on the basis of the light beam positions detected by the converging position detection unit.

15 According to the invention of aspect 28, the aberration measuring apparatus may further comprise an aberration measuring optical system (PH) through which the light beam for measuring the aberration fall on the projection optical system. The measuring unit may be

20 detachably held on the substrate stage, and the aberration measuring optical system is provided on the mask stage.

According to the invention of aspect 29, an aberration measuring method for measuring an aberration

25 of a projection optical system (PL) incorporated into an exposure apparatus for transferring onto a substrate (WH) an image of a pattern formed on a mask (R), comprises a

step for disposing an aberration measuring optical system (PH), for emitting a light beam for measuring the aberration fall upon the projection optical system, substantially in the same position as the mask is disposed, and a step for attaching, to a substrate stage (13) for holding the substrate, a measuring unit (UT') including a plurality of lens elements (L') for converging light beams for measuring an aberration that have passed through the projection optical system, a converging position detection unit (DET) for detecting each of positions of the light beams converged by the lens array, and a measuring device (PC) for measuring the aberration of the projection optical system on the basis of the light beam positions detected by the converging position detection unit.

According to the invention of aspect 30, an aberration measuring method may further comprise a step for removing the aberration measuring optical system after the light beam for measuring the aberration have fallen upon the projection optical system, and a step for removing the measuring unit from the substrate stage after measuring the aberration of the projection optical system.

According to the invention of aspect 31, an exposure method for transferring onto a substrate (WH) an image of a predetermined circuit pattern by the use of a projection optical system (PL), comprises a step of

measuring an aberration of the projection optical system by the use of the aberration measuring method of aspect 29 before transferring the circuit pattern onto the substrate.

5           According to the invention of aspect 32, a device manufacturing method including a step of transferring onto a substrate (WH) an image of a predetermined circuit pattern by the use of a projection optical system (PL), comprises a step of measuring an aberration of the  
10           projection optical system by the use of the aberration measuring method of aspect 29 before transferring the circuit pattern onto the substrate.

#### BRIEF DESCRIPTION OF THE DRAWINGS

15           FIG. 1 is a view showing a configuration of a projection exposure apparatus using a wavefront aberration measuring apparatus in a first embodiment of the present invention;

20           FIG. 2 is an enlarged view showing a configuration in the vicinity of a stage of the projection exposure apparatus shown in FIG. 1;

            FIG. 3 is a view showing a configuration of the wavefront aberration measuring apparatus in the embodiment of the present invention;

25           FIGS. 4A and 4B are views showing configurations of modified examples of the wavefront aberration measuring apparatus in the embodiment of the present

invention;

FIGS. 5A, 5B and 5C are diagrams each showing how a position of a converging point P shifts depending on a measuring position;

5        FIG. 6 is a conceptual view showing a relation between a measurement target wavefront W and an inclination  $W'$  of the wavefront;

10        FIG. 7 is a view showing a configuration in the vicinity of the stage of the projection exposure apparatus in a second embodiment of the present invention;

15        FIG. 8 is a view showing a configuration in the vicinity of the stage of the projection exposure apparatus in a third embodiment of the present invention; and

FIG. 9 is a view illustrating an architecture of a prior art wavefront aberration measuring apparatus.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

20        Embodiments of the present invention will hereinafter be described with reference to the accompanying drawings.

(First Embodiment)

25        FIG. 1 is a view showing a configuration of a projection exposure apparatus to and from which a wavefront aberration measuring unit UT can be attached and detached that will hereinafter be explained. The

projection exposure apparatus manufactures a semiconductor device formed with a circuit pattern. This projection exposure apparatus will be outlined. Laser beam LB0 emitted from a laser light source 1 are  
5 adjusted in profile by a beam profile adjusting optical system 2 into substantially-collimated laser beam LB1. The laser beam LB1 travels through an interference fringe reduction unit 4 for averaging interference fringes and enter a fly-eye lens 5. The interference fringe  
10 reduction unit is structured to enhance uniformity of illuminance on a reticle, of which the principle is disclosed in Japanese Patent Laid-Open Publication No.59-226317 by the present applicant. Laser beam IL2 exiting the fly-eye lens 5 is incident upon a field stop  
15 8 via a first relay lens 7A. A profile of the laser beam IL2 is adjusted by the field stop 8. The field stop 8 is disposed in a conjugate to a pattern forming surface of the reticle R and to an exposure surface of a wafer WH. Laser beam IL2 exiting an aperture of the field stop  
20 8 illuminates the reticle R (mask) formed with the circuit pattern through a second relay lens 7B, a mirror 9 and a condenser lens 10. The reticle R is placed on a stage 11, and, based on a command given from a main control system 16, a reticle stage control unit 21 moves the  
25 reticle stage 11. Then, a pattern image of the reticle R illuminated with the laser beam, is formed on the wafer WH defined as a substrate through a projection optical

system PL. A variety of patterns are sequentially formed  
 on the wafer WH by using a variety of reticles R in exchange,  
 thereby forming a semiconductor device. The wafer WH is  
 chucked in vacuum by a wafer holder 12 on a wafer stage  
 13. Further, wafer stage control unit 22 controls the  
 stage 13 so that the stage 13 is positioned and moved  
 stepwise at a high accuracy. An Input / Output unit 24  
 is a man-to-machine interface between the projection  
 exposure apparatus body and an operator. FIG. 2 is an  
 enlarged view showing the configuration in the vicinity  
 of the stage of the present projection exposure apparatus.  
 The wavefront aberration measuring unit UT is placed on  
 the stage 13 through the wafer holder 12. When placing  
 the unit UT on the wafer holder 12, the stage 13 is moved  
 in an -Z direction in order to expand a spacing between  
 the projection lens PL and the wafer holder 12. Next,  
 the stage 13 is moved in X- and Y-directions by the stage  
 control unit 22 so that the unit UT (particularly a  
 collimator lens CL of the unit UT) faces to the projection  
 lens PL. Note that the projection lens PL is used as a  
 measurement target optical system of which a wavefront  
 aberration is measured. Thus, in a state where the unit  
 UT is set in the face-to-face relation with the projection  
 lens PL, the wavefront aberration of the projection lens  
 PL is measured.

FIG. 3 is a view showing a configuration of the  
 wavefront aberration measuring unit UT in the first

embodiment of the present invention. A specific configuration for measuring the wavefront aberration of the projection lens PL by the use of the wavefront aberration measuring unit UT according to the present invention, will be explained. It is to be noted that the wavefront aberration measuring unit UT is, as described above, placed on the wafer holder 12 on the stage 13. When measuring the wavefront of the projection lens PL, the light beam of which a wavefront is spherical are incident as light beam for measuring the wavefront aberration upon the projection lens PL. The light beam of the spherical wave can be generated from a pinhole pattern by disposing a mask including the pinhole pattern in a position (on an object plane of a projection optical system) where the reticle is disposed and illuminating this mask with the laser beam IL2. An aberration measuring optical system is constructed of this mask. Further, a point light source may be used as a substitute for the pinhole pattern. Moreover, the exposure light source is used in the first embodiment for emitting the laser beam with which the mask is illuminated, however, other light source and other illumination optical system may also be separately provided. The light beam of the spherical wave is incident on projection lens PL and exit the same lens PL. The light beam exited from the projection lens PL are collimated by the collimator lens CL. Then, the collimated light beam is converged by a converging lens

L, and an aperture AP defined as an aperture stop disposed behind the lens L transmits only a part of the converged light beam. The part of light beam traveling through the aperture AP are converged as a converging point P on an  
5 imaging surface IP of a converging position detection unit DET such as a two-dimensional CCD. The converging point P may also be detected, without being limited to the two-dimensional CCD, by a scan using a one-dimensional CCD or by rotating the one-dimensional CCD,  
10 or further by executing two-dimensional scans using a sole optical sensor. Herein, if an aberration exists in the projection lens PL, a position of the converging point P is different from a case in which no aberration occurs in the projection lens PL. Namely, the position of the  
15 converging point when the aberration exists in the projection lens PL deviates sideways on the CCD surface from an ideal converging point with no aberration in the projection lens PL. Then, a moving unit M moves the aperture AP to scan over the entire surface of the  
20 measurement target wavefront while keeping mutual positional relations between the collimator lens CL, the converging lens L and the converging position detection unit DET. In such a case, it is preferable that the collimator lens CL, the converging lens L and the  
25 converging position detection unit DET be accommodated in an integral unit UT. Further, the converging position of the light beam transmitting the projection lens PL,



i.e., the imaging surface IP is conjugate to the surface of the wafer WH. Moreover, the wavefront aberration measuring unit implies a configuration containing the mask formed with the pinhole pattern or the point light source, the lens L and the converging position detection unit DET.

Thus, the moving unit M moves the aperture AP to scan over the entire surface of the measurement target wavefront while keeping the mutual positional relations between the collimator lens CL, the converging lens L and the converging position detection unit DET, whereby it is feasible to detect the lateral shift, on the CCD surface, of the converging point when the aberration exists in the projection lens from the ideal converging point with no aberration in the projection lens PL on the entire measurement target wavefront.

Note that a central area of the converging lens L is used when converging (the laser beams in the vicinity of an optical axis AX) on the central part of the measurement target wavefront, while a peripheral area of the converging lens L is used when converging (marginal light beam) on a peripheral portion of the measurement target wavefront in the first embodiment. Thus, different areas of the converging lens L are different, and hence, if this lens L has the aberration, the aberration might have an influence on the measured result. Such being the case, for reducing the influence by the

aberration of the converging lens L, it is preferable that the converging lens L be moved with respect to the collimator lens CL and the detection unit DET while keeping the mutual positional relation between the lens L and the aperture AP. It is, however, more preferable that, as shown in FIG. 4A, a small-aperture lens L for converging a part of light beam of the measurement target wavefront, be used as the converging lens L. in the case of using this small-aperture lens L, the moving unit M moves the lens L so as to scan over the entire measurement target wavefront.

FIG. 4B shows a modified example of the configuration in FIG. 4A, wherein the entire measurement target wavefront is scanned while keeping the mutual positional relations between the lens L, the aperture AP and the detection unit DET which are housed in the unit UT. A measuring system S is constructed of the lens L, the aperture AP and the detection unit DET, and is moved within the unit UT by the moving unit M. According to this configuration, the detection unit in FIG. 4A can be downsized.

Next, a process of calculating the aberration of the measurement target optical system on the basis of an output signal transmitted from the converging position detection unit DET, will be explained. Described herein is a case where the wavefront aberration measuring unit takes the configuration shown in FIG. 4B. FIGS. 5A, 5B

and 5C show measured results at three points within an arbitrary area of the measurement target wavefront, more specifically, how the converging point P on the detection unit DET changes when the measuring system S is moved to

5 the three points. Herein, a plane of the imaging surface IP is set as an X-Y plane. If the measurement target wavefront is an ideal wavefront, i.e., a wavefront (spherical surface) with no aberration, the converging point P exists at a center O of the detection unit DET

10 wherever the measuring system S moves within the measurement target wavefront. The actual measurement target wavefront, however, has the aberration, viz., a deviation (a difference in inclination of the wavefront) from the ideal wavefront. Accordingly, as shown in FIGS.

15 5A, 5B and 5C, depending on each converging point, the deviation at that converging point appears as a change (lateral shift) of the position of the converging point P in the detection unit DET. The positional deviation of the converging point P from the center corresponds to

20 differential information of the measurement target wavefront, and therefore a value obtained from the positional deviation of the converging point P at each measuring point for every movement is integrated in sequence with respect to the entire measurement target

25 wavefront, whereby an aberration of the measurement target wavefront can be calculated.

FIG. 6 illustrates a concept of the calculating

process described above. FIG. 6 shows how the measurement is conducted consecutively at the respective moving points. As discussed above, a shift quantity of the converging point P due to an inclination of a wavefront W' at each measuring point is sequentially integrated by the use of an arithmetic processor PC, thereby making it feasible to calculate the measurement target wavefront W. The aberration of the measurement target optical system can be obtained.

In the case of measuring the aberration of the measurement target optical system by using the configuration shown in FIG. 4A, a plurality of imaging areas are set on the imaging surface IP, and the lens L and the aperture AP are positioned with respect to each imaging area by the moving unit M. The position of the converging point at which the lens L converges the actual measurement target wavefront is changed from the center of the imaging area at which the lens L converges the ideal measurement target wavefront, and the change is detected. The aberration can be measured by detecting this positional change quantity. Note that the calculation of the measurement target wavefront W is the same as what has been described above.

Thus, at one point on the image forming surface through the projection lens PL, the positional deviation of each converging point of the measurement target wavefront from each converging point of the ideal

wavefront, is measured. A spherical aberration and an astigmatic difference can be thereby obtained as the aberrations of the projection lens PL.

Further, the stage control unit 22 drives the stage  
 5 13 so that the unit UT moves to the plurality of points on the image forming surface through the projection lens PL. Then, at each of the plurality of points within the image forming surface of the projection lens PL, the moving unit M is controlled so that the entire measurement  
 10 target wavefront is scanned through the lens L and the aperture AP within the unit UT or the measuring system S. With this operation, at each of the plurality of points within the image forming surface of the projection lens PL, it is feasible to measure the positional  
 15 deviation of each converging point of the measurement target wavefront from each converging point of the ideal wavefront, and a comma, a curvature of field, a distortion and a astigmatism can be obtained as aberrations of the projection lens PL.

20 Note that the collimator lens CL for collimating the light beam of the measurement target wavefront is incorporated into the unit UT the first embodiment. The collimator lens CL may, however, be provided in a unit different from the unit UT. Moreover, as a matter of  
 25 course, the light beam of spherical wave that travels through the measurement target optical system PL may be measured by the present apparatus without using the

collimator lens CL.

As described above, the unit UT is placed on the wafer holder 12 on the stage 13, and the moving unit M moves the lens L and the aperture AP in the unit UT or  
5 the measuring system S, whereby the wavefront aberration of the projection lens PL can be simply measured. After measuring the wavefront aberration of the projection lens PL, the aberration measuring optical system (mask for measurement) is removed from the stage, and the unit UT  
10 is also removed from the stage 13. A weight of the stage 13 when used for exposure is reduced by removing the unit UT out of the stage 13. Further, the aberration can be measured by using the exposure light source on the projection exposure apparatus, and hence the apparatus  
15 can be downsized. Moreover, a space for the measurement using a separate interferometer is not required, and the aberration can be measured at a high accuracy because of using the single lens as a lens element. In addition, the projection lens PL can be adjusted based on the  
20 measured result in the state where the present wavefront aberration measuring unit is placed on the stage 13 of the projection exposure apparatus. In this case, if combined with an auto lens adjusting device, etc., the result of measuring the wavefront aberration is fed back  
25 to the auto lens adjusting device, and a spacing between the lenses can be adjusted. What is exemplified as the auto lens adjusting device may be a moving mechanism for

changing the spacing between the lens elements by minutely moving in an optical-axis direction at least one of the lens elements constituting the projection lens PL, and a pressure adjusting mechanism for adjusting an air pressure between the lens elements, and so on. With these mechanism, the wavefront aberration of the projection optical system can be automatically corrected, and the image forming characteristic can also be enhanced.

(Second Embodiment)

FIG. 7 is an explanatory view showing an outline of configuration in the vicinity of the stage of the projection exposure apparatus in a second embodiment. The same components of the projection exposure apparatus in the second embodiment as those in the first embodiment, are marked with the like numerals, of which the repetitive explanations and illustrations are omitted.

In the first embodiment the wavefront aberration of the projection lens PL can be measured by the use of the exposure light source on the exposure apparatus. In this case, it is desirable that a reticle for measuring the aberration of the projection lens, which includes a point light source, i.e., a pinhole be provided in the position of the reticle R. Accordingly, the laser beam IL emitted from the exposure light source is converted into light beam of spherical wave by the pinhole of the reticle R. Herein, an enhancement of the accuracy of measuring the wavefront aberration of the projection lens

PL may involve decreasing a diameter of the pinhole and making the spherical waves generated at the pinhole approximate to ideal spherical waves. When the diameter of the pinhole becomes small, however, a quantity of  
5 transmitted light beam decreases, a contrast on the imaging surface is lowered, with the result that a longer period of time is needed for the measurement. Further, because the projection lens aberration measuring reticle provided with the pinhole is used when measuring the  
10 wavefront aberration of the projection lens, and because a reticle for exposure is used when executing a normal pattern exposure, it is required that the reticle be re-placed on the reticle stage and be aligned each time the aberration is measured or the pattern exposure is  
15 carried out; and therefore, the throughput might decline.

The projection exposure apparatus in the second embodiment is contrived to obviate the above problem, and, as shown in FIG. 7, for instance, the reticle stage 11 has a pinhole PH for measuring the wavefront aberration  
20 of the projection lens.

The process of manufacturing the semiconductor device by the use of the reticle R formed with the circuit pattern is the same as the process described in the first embodiment, and its explanation is therefore omitted.  
25 Next, a process of measuring the wavefront aberration of the projection lens PL will be described. When measuring the wavefront aberration of the projection lens PL, the



reticle stage control unit 21 drives the reticle stage 11 in a state of being mounted with the reticle R formed with the circuit pattern, and the pinhole PH is thereby moved onto the optical axis AX, wherein the aberration is measured with the light beam from the pinhole serving as a point light source. To start with, the wavefront aberration measuring unit UT (of which the construction is the same as in the first embodiment) is placed on the stage 12 via the wafer holder 12. Next, the moving unit M moves the lens L and the aperture AP or the measuring system S so that the entire measurement target wavefront from the converging lens is scanned through the lens L and the aperture AP within the unit UT or the measuring system S. As described above, the positional deviation of each converging point of the measurement target wavefront is obtained, and the arithmetic processor PC executes the integrating operation explained above. Herein, the converging position of the light beam transmitting the projection lens PL is conjugate to the surface of the wafer WH. Then, obtained data about the wavefront aberrations (the comma, the astigmatism, the spherical aberration, etc.) of the projection lens PL are fed back to a lens control unit LC. The lens control unit LC adjusts the spacing between the respective lens elements constituting the projection lens PL or an air pressure in that spacing therebetween on the basis of the wavefront aberration data, thereby restraining, within

a predetermined range, a quantity of the aberration of the wavefront transmitting the projection lens PL. It is to be noted that the unit UT may take a configuration of being detachably provided directly on the wafer holder  
 5 12 or the stage 13, or assembled to the stage 13, and further a configuration of being detachably provided on the side surface of the stage 13.

Moreover, in the second embodiment, the light beam passing through the pinhole provided in the reticle stage  
 10 is used as the light source, however, the present invention is not limited to this mode. The reticle stage may be provided with an area for diffusing and transmitting the light beam from the light source 1, the area being formed in a so-called lemon-skin state, and  
 15 the light beam penetrating this lemon-skin area may be used as a light source for measuring the wavefront aberration. The lemon-skin area has a function of diffusing the transmission light beam as a glass-like diffusion plate has, and the light beam transmitting this  
 20 area may be conceived as substantially-collimated light beams of a plurality of spherical waves emitted from a plurality of point light sources. Further, the pinhole or the lemon-skin area may be, without being limited to the example of its being provided in the reticle stage,  
 25 provided in the reticle as in the first embodiment.

As discussed above, when the pinhole diameter is reduced, the quantity of the transmitted light beam

decreases, and hence, though the measuring time becomes longer, the measurement accuracy can be enhanced. By contrast, when pinhole diameter is enlarged, the configuration of the spherical waves generated at the pinhole becomes less approximate to the ideal spherical waves, and therefore, though the measuring accuracy declines, the measuring time can be made shorter with a larger quantity of the transmitted light beam. Hence, it is desirable that the reticle stage 11 or the reticle R be formed with the pinholes having a plurality of sizes, and that the pinhole be alternatively selected and used corresponding to a target measuring accuracy. For example, if the setting of the projection exposure apparatus has already been completed and the exposures of the circuit patterns are sequentially executed, a main purpose is to measure changes with an elapse of time in terms of optical characteristics (image forming characteristics such as a magnification and a focal position, and fluctuations of transmittance) of the projection lens. It is therefore desirable that the wavefront measurement be performed at a proper accuracy for a short period of time when the light beam transmits the projection lens a predetermined number of times. Further, if the projection lens or at least one of the lens elements constituting the projection lens is replaced with other lens, it is desirable that a high-precision wavefront measurement be conducted taking

a considerable period of time in the case of changing a wavelength of the light source. Thus, the pinholes having the plurality of sizes are formed, and the pinhole having the size optimal to the purpose can be thereby easily selected. Moreover, the exposure light source is used in the second embodiment as the laser beams with which the reticle stage is illuminated, however, other light source and other illumination optical system may separately be provided.

#### 10 (Third Embodiment)

FIG. 8 is a view showing an outline of configuration in the vicinity of the stage of the projection exposure apparatus in a third embodiment. The same components of the projection exposure apparatus in the third embodiment as those in the first embodiment, are marked with the like numerals, of which the repetitive explanations and illustrations are omitted.

The process of manufacturing the semiconductor device by the use of the reticle R formed with the circuit pattern, is the same as the process described in the first embodiment, and therefore its explanation is omitted. Next, the process of measuring the wavefront aberration of the projection lens PL will be explained.

The wafer stage control unit 22 controls driving of the wafer stage 13 so that the transmitted wavefront from through the projection lens PL is incident on an aberration measuring unit UT' detachably provided

through an attaching/detaching mechanism D on a side surface of the stage 13. The aberration measuring unit UT' comprises a two-dimensional lens array including a plurality of lens elements L', two-dimensionally arrayed, for converging the light beams of the spherical waves generated at the pinholes PH and transmitting the projection optical system PL, and the converging position detection unit DET for detecting each of positions where the plurality of lens elements L' converge the light beams. Further, as in the first embodiment, the wavefront aberration measuring unit implies a configuration containing the mask formed with the pinhole PH and the pattern, the two-dimensional lens array L' and the converging position detection unit DET.

Note that the stage 11 of the reticle R, it is preferable, as stated in the embodiments discussed above, without being confined to the pinhole, be provided with any one of the pinhole the lemon-skin area. More preferably, it is desirable that the plurality of pinholes having different sizes be provided, and, as in the second embodiment, the pinhole suited to the measuring purpose be selected. Thus, the stage or the reticle including any one of the pinhole and the lemon-skin area constitutes the aberration measuring optical system.

The light beam transmitting the projection optical system PL are collimated by the collimator lens CL. Then,

the parallel light beam is incident on the two-dimensional lens array where the minute lens elements  $L'$  are arrayed two-dimensionally. If the measurement target wavefront of the incident light beam has a deviation from the ideal wavefront, i.e., the wavefront with no aberration caused in the projection lens, this deviation appears to be a positional deviation of the converging position of the measurement target wavefront from the converging position of the ideal wavefront on the converging position detection unit DET. The arithmetic processor PC calculates a wavefront aberration of the projection lens PL on the basis of the positional deviation of the converging point of each individual lens element  $L'$  of the two-dimensional lens array.

Thus, at one point on the image forming surface through the projection lens PL, the positional deviation of each measuring point of the measurement target wavefront from each converging point of the ideal wavefront, is measured, thereby making it possible to obtain the spherical aberration and the astigmatic difference as the aberrations of the projection lens PL. Further, the stage control unit 22 drives the stage 13 so that the unit UT moves to a plurality of points on the image forming surface through the projection lens PL. Then, at each of the plurality of points on within the image forming surface through the projection lens PL,

there is measured the positional deviation of each measuring point of the measurement target wavefront from each converging point of the ideal wavefront, and the comma, the curvature of field, the distortion and the  
 5 astigmatism can be obtained as the aberrations of the projection lens PL from these results of the respective measurements.

Then, the wavefront aberration data about the thus obtained comma, curvature of field, distortion and  
 10 astigmatism of the projection lens PL, are fed back to the lens control unit LC. The lens control unit LC, based on these pieces of wavefront aberration data, adjusts the spacing between the lens elements constituting the projection lens PL or the air pressure in that spacing,  
 15 thereby restraining within the predetermined range a quantity of aberration of the wavefront passing through the projection lens PL. Note that the unit UT' may take a configuration of being detachably provided on the wafer holder 12 or the stage 13, or assembled to the stage 13,  
 20 and further a configuration of provided in the vicinity of the stage 13.

The accuracy of measuring the aberration of the projection lens PL can be enhanced by increasing a measuring resolution of the converging position  
 25 detection unit DET and a position control accuracy of the moving unit M or the wafer stage 13. For instance, if the detecting resolution of the converging position

detection unit is on the order of  $10 \sim 20 \mu\text{m}$ , it may be sufficient that the wafer stage 13 is controlled at a pitch of 1mm in the projection exposure apparatus for an exposure of a  $5\text{mm} \times 5\text{mm}$  area.

5           Further, an areal size of the aperture AP may be made variable in the first embodiment. In this case, the resolution becomes higher as the aperture is more stopped down, and hence the measuring accuracy is enhanced.

10           The embodiments discussed above may be combined as the necessity arises. In each of the embodiments, the wavefront aberration measuring unit is detachably provided on the stage 13, and may also be, as an attaching/detaching mechanism thereof, made detachable by providing the stage 13 with a notched portion and this  
15           measuring unit with an engagement member engaging with this notched portion. Moreover, in the case where the measuring unit is so constructed as to be attachable to and detachable from the stage 13, as a substitute for the whole measuring unit, some elements thereof, e.g., the  
20           collimator lens CL and the lens L may be detachably structured, while the detection unit DET may be fixed to the stage 13. Reversely, for instance, the collimator lens CL and the lens L may be fixed to the stage 13, while the detection unit DET may be detachably constructed.

25           In each of the embodiments, the wavefront aberration of the projection lens PL is measured in the state of having been assembled to the exposure apparatus,



and may also be measured before being assembled to the exposure apparatus. A timing for measuring the wavefront aberration may be any one of timings when the wafer is replaced and the reticle is replaced, and an interval of a predetermined time, or timings other than these timings may also be adopted. On that occasion, the measuring accuracy, as described above, can be selected. Further, in the respective embodiments, the exposure light source is used as the light source for measuring the aberration, however, other light source may also be used. the exposure light source may involve the use of a g-line (436 nm), an i-line (365 nm), a KrF excimer laser (248 nm), an ArF excimer laser (193 nm), an F<sub>2</sub> laser (157 nm), and higher-harmonics of a metal vapor laser and a YAG laser.

Note that the exposure apparatus in this embodiment can be applied to the scan type exposure apparatus (USP5, 473, 410) for exposing to the light beam of a mask pattern by synchronously moving the mask and the substrate, or the step-and-repeat type exposure apparatus for exposing to the mask pattern in a state where the mask and the substrate are set stationary, and moving the substrate stepwise. The exposure apparatus is not limited to the application for manufacturing the semiconductor and can be applied widely to the use as a liquid crystal exposure apparatus for exposing, e.g., angular glass plate to the light beam of a liquid crystal display device pattern,

and the use as an exposure apparatus for manufacturing a thin-film magnetic head.

As for a magnification of the projection lens as the measurement target optical system, not only a  
5 reduction system but also an equal-magnification and an enlargement system may be adopted. The projection lens may involve the use of a material such as quartz and fluorite as a glass material that transmits far  
10 ultraviolet rays if using the far ultraviolet rays such as excimer lasers. In the case of using the  $F_2$  laser and X-rays, there may be a catadioptric system or refracting optical system (a reflecting type of reticle is likewise used).

When using the far ultraviolet rays are used as the  
15 excimer laser, an optical path between the light source and the substrate is purged by an inactive gas. Thus, in the case of using the far ultraviolet rays, the interior of the wavefront aberration measuring unit UT may also be purged by the inactive gas. What is used as an inactive  
20 gas may be helium, neon, argon, krypton, xenon, radon, etc.. if the wavelength of the exposure light beam is a wavelength (e.g., the I-line, KrF, etc.) that is not absorbed by oxygen, there may be used chemically clean dry air (which is the air from which substances becoming  
25 a cause of hazing of the lens, e.g., ammonium ions, etc floating within a clean room are removed, or the air of which a humidity is 5% or under).

As discussed above, the exposure apparatus and the aberration measuring unit in this embodiment are manufactured by assembling a variety of subsystems including the respective elements given in claims of the invention of the present application so as to keep the  
5 predetermined mechanical, electrical and optical accuracies. Ensuring these accuracies entails, before and after the assembly, making adjustments for attaining the optical accuracy with respect to the variety of  
10 optical systems, adjustments for attaining the mechanical accuracy with respect to the variety of mechanical systems, and adjustments for attaining the electrical accuracy with respect to the variety of electrical systems. A process of the assembly into the  
15 exposure apparatus from the variety of subsystems includes mechanical connections between the variety of subsystems, wire connections of an electric circuit and pipe connections of an atmospheric pressure circuit.

Before the process of the assembly into the exposure apparatus from the variety of subsystems, as a matter of course, there are assembling processes of the individual subsystems. Upon an end of the process of the assembly into the exposure apparatus from the variety of  
20 subsystems, a total adjustment is executed, thus ensuring the various accuracies as the whole exposure apparatus.  
25 Note that the exposure apparatus, it is desirable, be manufactured in the clean room where a temperature and

a degree of cleanness are managed. Further, the semiconductor device is manufactured by a step of designing a function and a performance of the device, a step of manufacturing the reticle based on this design step, a step of manufacturing the wafer by the use of a silicon material, a step of exposing the wafer to the light beam of the reticle pattern by the exposure apparatus in the embodiments discussed above, a device assembling step (containing a dicing step, a bonding step and a package step), and an inspection step.

#### Industrial Applicability

As explained above, according to the invention of aspect 1, there is provided the converging position detection unit for detecting the positional deviation of the converging position of a part of the light beam passing through the aperture stop on the predetermined surface, and the aperture stop is moved in such a direction as to intersect the optical axis. Accordingly, the aberration of the measurement target optical system can be measured with a high precision in a small-sized and simple configuration by using neither the interferometer nor the two-dimensional lens array.

According to the invention of aspect 2, the converging lens converges a part of the light beam, and the moving unit moves the converging lens and the aperture stop as an integral element in such a direction as to intersect the optical axis. Hence, the converging lens

may be of a small size and is therefore easy to manufacture, and the cost thereof is low. Further, the light beam is always converged by the use of the entire surface of the small-sized converging lens, and a measurement error due  
5 to an influence of the aberration of the converging lens itself can be reduced.

According to the invention of aspect 3, the wavefront aberration of the lens used in the projection exposure apparatus for manufacturing the semiconductor  
10 device, etc., can be easily measured.

According to the invention of aspect 4, it is possible to precisely quickly measure the aberration by the use of the spherical waves penetrating the pinhole pattern.

15 According to the invention of aspect 5, there may be used the light beam from the illumination optical system for illuminating the reticle having the predetermined circuit pattern with the light beam.

According to the invention of aspect 6, the  
20 aberration of the measurement target optical system can be measured with a high accuracy in the small-sized and simple configuration by using neither the interferometer nor the two-dimensional lens array.

According to the invention of aspect 7, the  
25 converging lens may be of a small size and is therefore easy to manufacture, and the cost thereof is low. Further, the light beam is always converged by the use of the entire

surface of the small-sized converging lens, and a measurement error due to an influence of the aberration of the converging lens itself can be reduced.

According to the invention of aspect 8, the  
5 wavefront aberration of the projection optical system used in the projection exposure apparatus for manufacturing the semiconductor device, etc., can be easily measured.

According to the invention of aspect 9, the  
10 aberration can be precisely quickly measured by the use of the spherical waves penetrating the pinhole pattern.

According to the invention of aspect 10, the  
aberration of the projection optical system for forming a predetermined circuit pattern on the substrate can be  
15 measured with a high accuracy in the small-sized and simple configuration by using neither the interferometer nor the two-dimensional lens array.

According to the invention of aspect 11, the  
aberration of the projection optical system can be  
20 precisely quickly measured by the use of a generation member for generating the light for measuring the aberration.

According to the invention of aspect 12, the  
aberration of the projection optical system can be  
25 precisely quickly measured by the use of the spherical waves penetrating the pinholes.

According to the invention of aspect 13, the

aberration of the projection optical system can be precisely quickly measured by substantially-collimated light beam of a multiplicity of spherical wave transmitting in diffusion a transmission member.

5           According to the invention of aspect 14, the wavefront aberration of the projection optical system used in the projection exposure apparatus for manufacturing the semiconductor device, etc., can be easily measured.

10           According to the invention of aspect 15, the aberration can be precisely quickly measured by the use of the spherical waves penetrating the pinhole pattern.

          According to the invention of aspect 16, the control unit, based on a result of measuring the aberration,  
15       adjusts a spacing between lens elements of the projection optical system, and thus corrects the wavefront aberration of the projection optical system, whereby image forming characteristics can be enhanced.

          According to the invention of aspect 17, the  
20       aberration of the projection optical system can be easily measured simply by installing the wavefront aberration measuring unit on, e.g., a wafer stage of the projection exposure apparatus. Further, the light source of the exposure apparatus can be used as it is, and hence the  
25       apparatus can be downsized.

          According to the invention of aspect 18, the aberration of the projection optical system can be

measured with a high accuracy in the small-sized and simple configuration by using neither the interferometer nor the two-dimensional lens array. It is therefore feasible to enhance the image forming performance and manufacture a device with a high resolution.

According to the invention of aspect 19, the wavefront aberration of the projection optical system used in the projection exposure apparatus for manufacturing the semiconductor device, etc., can be easily measured. It is therefore feasible to enhance the image forming performance and manufacture the device with the high resolution.

According to the invention of aspect 20, the aberration of the projection optical system can be precisely quickly measured by the use of the generation member for generating the light beam for measuring the aberration, and hence the exposure with an enhanced throughput can be executed.

According to the invention of aspect 21, it is possible to easily measure the aberration of the projection optical system and correct the aberration of the projection optical system on the basis of the measured result, whereby an exposure method capable of exhibiting a high image forming performance can be provided.

According to the invention of aspect 22, it is possible to easily measure the wavefront aberration of the projection optical system and correct the wavefront



aberration of the projection optical system on the basis of the measured result, whereby the exposure method capable of exhibiting the high image forming performance can be provided.

5           According to the invention of aspect 23, the aberration measuring unit can be detachably held in the exposure apparatus for manufacturing the semiconductor device, etc., and it is therefore easy to install or replace this aberration measuring unit when measuring the  
10           aberration.

          According to the invention of aspect 24, the aberration measuring optical system and the measuring unit can be easily detachably installed in the exposure apparatus.

15           According to the invention of aspect 25, a mask can be easily detachably placed on a mask stage, and the measuring unit can be easily detachably attached to a substrate stage.

          According to the invention of aspect 26, the mask  
20           having the pinhole pattern can be easily detachably provided, and hence a pinhole having a diameter proper to the aberration measurement can be easily selected.

          According to the invention of aspect 27, the aberration of the projection optical system can be easily  
25           measured simply by installing the wavefront aberration measuring unit on, e.g., the wafer stage of the projection exposure apparatus. Further, the light source of the

exposure apparatus can be used as it is, and hence the aberration measuring unit can be downsized.

According to the invention of aspect 28, the aberration of the projection optical system can be  
5 precisely quickly measured by the use of the light beam from the aberration measuring optical system provided on the mask stage. Further, the measuring unit can be easily detachably provided on the substrate stage.

According to the invention of aspect 29, the  
10 aberration of the projection optical system can be readily measured simply by installing the measuring unit on the wafer stage of the projection exposure apparatus by the use of the light beam from the aberration measuring optical system. Moreover, the light source of the  
15 exposure apparatus can be used as it is, and hence the apparatus can be downsized.

According to the invention of aspect 30, a weight of the substrate stage can be reduced by removing the measuring unit.

20 According to the invention of aspect 31, the aberration of the projection optical system is measured before transferring the circuit pattern, and therefore the pattern can be precisely transferred.

According to the invention of aspect 32, the  
25 aberration of the projection optical system is measured before transferring the circuit pattern, and hence the device can be manufactured exactly with the high

precision.

WHAT IS CLAIMED IS:

1. An aberration measuring apparatus comprising:  
a converging lens disposed on the light path of  
light beam to converge light beam traveling through a  
5 measurement target optical system on a predetermined  
surface;

an aperture stop disposed on the light path of light  
beam to transmit a part of the light beam;

10 a moving unit connected the aperture stop to move  
said aperture stop within the light beam;

a converging position detection unit disposed on  
the predetermined surface to detect a positional  
deviation of a converging position of a part of the light  
beams traveling through said aperture stop on the  
15 predetermined surface; and

an arithmetic processing unit connected the  
converging position detection unit to calculate an  
aberration of said measurement target optical system on  
the basis of an output signal from said converging  
20 position detection unit.

2. An aberration measuring apparatus according to  
claim 1, wherein said converging lens converges a part  
of the light beams, and

25 said moving unit moves said converging lens  
integrally with said aperture stop in the direction  
intersecting the optical axis of the light beam.

3. An aberration measuring apparatus that measures an aberration of a projection optical system that transfers onto a substrate, an image of a predetermined circuit pattern formed on a mask, comprising:

an aberration measuring optical system disposed on the object plane side of the projection optical system to emit a light beam which measures the aberration upon said projection optical system;

a plurality of lens elements, two-dimensionally arrayed, disposed on the image plane side of the projection optical system to converge the light beams through said projection optical system;

a converging position detection unit disposed on the image plane of the lens elements to detect each of positions of the light beams converged by said plurality of lens elements; and

a measuring device connected the converging position detection unit to measure the aberration of said projection optical system on the basis of the converged light positions detected by said converging position detection unit.

4. An aberration measuring apparatus according to claim 3, wherein said aberration measuring optical system includes:

a mask which measures the aberration, disposed

substantially in the same position as said mask formed with the predetermined circuit pattern is disposed and having a pinhole pattern; and

an illumination optical system that illuminates  
5 said mask which measures the aberration with the light beam.

5. An aberration measuring apparatus according to claim 4, wherein said illumination optical system is an  
10 illumination optical system that illuminates the predetermined circuit pattern with the light beam.

6. An aberration measuring method comprising:  
converging light beam traveling through a  
15 measurement target optical system on a predetermined surface by the use of a converging lens;  
making an aperture stop transmit a part of the light beam;  
moving said aperture stop within the light beam;  
20 detecting a positional deviation of each of a converging position of a part of the light beam traveling through said aperture stop on the predetermined surface by the use of a converging position detection unit; and  
calculating an aberration of said measurement  
25 target optical system on the basis of an output signal obtained in said converging position detecting step.

7. An aberration measuring method according to claim 6, wherein a part of the light beam is converged in said converging step, and

5 said converging lens is moved integrally with said aperture stop in the direction intersecting the optical axis of the light beam in said moving step.

8. An aberration measuring method of measuring an aberration of a projection optical system that forms, on  
10 a substrate, an image of a predetermined circuit pattern formed on a mask through the projection optical system, comprising:

converging the light beams which measures the aberration that have passed through said projection  
15 optical system by the use of a plurality of lens elements;

detecting each of positions of the light beams converged by said plurality of lens elements; and

measuring the aberration of said projection optical system on the basis of the detected light positions.  
20

9. An aberration measuring method according to claim 8, wherein the light beam which measures the aberration is light beam from a pinhole pattern on a mask, which measures the aberration, disposed substantially in  
25 the same position as the said mask is disposed.

10. A projection exposure apparatus comprising:

an illumination optical system which illuminates  
a predetermined circuit pattern with the light beam;

a projection optical system which forms the circuit  
pattern illuminated with the light beam on a substrate;

5 and

an aberration measuring apparatus, claimed in claim  
1, which measures an aberration of said projection  
optical system.

10 11. A projection exposure apparatus comprising:  
an illumination optical system which illuminates  
a mask having a predetermined circuit pattern with the  
light beam;

a stage which supports said mask;

15 a projection optical system which forms on said  
substrate an image of the circuit pattern illuminated  
with the light beam; and

an aberration measuring apparatus, claimed in claim  
1, which measures an aberration of said projection  
20 optical system,

wherein said stage or said mask has a generation  
member to generate light beam which measures the  
aberration of said projection optical system.

25 12. A projection exposure apparatus according to  
claim 11, wherein said generation member is a pinhole  
pattern which convert the light beam from said



illumination optical system into spherical waves.

13. A projection exposure apparatus according to claim 11, wherein said generation member is a  
5 transmission member which transmits in diffusion the light beam from said illumination optical system.

14. A projection exposure apparatus having a projection optical system which transfers onto a  
10 substrate an image of a circuit pattern formed in a mask, comprising:

an aberration measuring optical system disposed on an image plane side of the projection optical system to emit a light beam which measure the aberration upon said  
15 projection optical system;

a lens array elements disposed on an image plane side of the projection optical system to converge the light beams which measure the aberration through said projection optical system; and

20 a converging position detection unit adapted to the lens element to detect each of positions of the light beams converged by said lens array.

15. A projection exposure apparatus according to claim 14, wherein said aberration measuring optical system includes:

a mask which measures the aberration, disposed

substantially in the same position as said mask formed with the predetermined circuit pattern is disposed and having a pinhole pattern; and

an illumination optical system which illuminates  
5 said mask which measures the aberration with the light beam.

16. A projection exposure apparatus according to claim 14, further comprising a control unit connected the  
10 converging position detection unit to control a position of at least one of optical members constituting said projection optical system on the basis of a detected result given from said converging position detection unit.

17. A projection exposure apparatus according to claim 14, further comprising a substrate stage which  
15 holdes said substrate,

wherein at least said lens array or said converging  
20 position detection unit is detachably provided on said substrate stage.

18. A device manufacturing method, comprising:  
measuring an aberration of said projection optical  
25 system by the use of said aberration measuring method claimed in claim 6; and

transferring an image of a predetermined circuit

pattern onto a substrate by the use of a projection optical system.

19. A device manufacturing method, comprising:

5       measuring an aberration of said projection optical system by the use of said aberration measuring method claimed in claim 8; and

10       transferring an image of a predetermined circuit pattern onto a substrate by the use of a projection optical system.

20. An exposure method comprising:

15       exposing a substrate to the light beam of a predetermined circuit pattern in a way of projecting the circuit pattern on said substrate by the use of said projection exposure apparatus claimed in claim 11.

21. An exposure method for transferring onto a substrate an image of a predetermined circuit pattern by the use of a projection optical system, comprising:

20       making light beam which measures an aberration incident upon said projection optical system before transferring the circuit pattern onto said substrate;

25       converging the light beam which measures the aberration that have passed through said projection optical system by the use of a plurality of lens elements two-dimensionally arrayed;

detecting each of positions of the light beams  
converged by said plurality of lens elements;

measuring the aberration of said projection optical  
system on the basis of the detected positions of the light  
5 beams; and

correcting the aberration of said projection  
optical system on the basis of the measured aberration.

22. An exposure method according to claim 21,  
10 wherein the aberration is a wavefront aberration of said  
projection optical system.

23. An exposure apparatus comprising:

a projection optical system which transfers onto  
15 a substrate an image of a pattern formed on a mask:

a holding mechanism adapted to a exposure apparatus  
body to detachably hold said aberration measuring  
apparatus claimed in claim 3.

24. An exposure apparatus according to claim 23,  
20 wherein said holding mechanism includes:

a first holding member which holds an aberration  
measuring optical system; and

a second holding member which holds a measuring unit  
25 having a plurality of lens elements, a converging  
position detection unit and a measuring device.

25. An exposure apparatus according to claim 24,  
wherein said first holding member is a mask stage which  
holds said mask, and

5       said second holding member is a substrate stage  
which holds said substrate.

26. An exposure apparatus according to claim 24,  
wherein said aberration measuring optical system is a  
mask for measurement, formed with a pinhole pattern which  
10       measures the aberration.

27. An aberration measuring apparatus that measures  
an aberration of a projection optical system which  
transfers onto a substrate an image of a pattern formed  
15       on a mask, comprising:

      a measuring unit detachably provided on an exposure  
apparatus including a mask stage which holds said mask,  
said projection optical system, and a substrate stage  
which holds said substrate,

20       wherein said measuring unit includes:

      a plurality of lens elements, two-  
dimensionally arrayed, disposed on the image plane  
side of the projection optical system to converge  
the light beams through said projection optical  
25       system;

      a converging position detection unit  
disposed on the image plane of the lens elements

to detect each of positions of the light beams  
converged by said plurality of lens elements; and  
a measuring device connected the converging  
position detection unit to measure the aberration  
of said projection optical system on the basis of  
the light positions detected by said converging  
position detection unit.

28. An aberration measuring apparatus according to  
claim 27, further comprising an aberration measuring  
optical system through which the light beam which  
measures the aberration fall on said projection optical  
system,

wherein said measuring unit is detachably held on  
said substrate stage, and

said aberration measuring optical system is  
provided on said mask stage.

29. An aberration measuring method which measures  
an aberration of a projection optical system incorporated  
into an exposure apparatus which transfers onto a  
substrate an image of a pattern formed on a mask,  
comprising:

disposing an aberration measuring optical system,  
to emits a light beam which measures the aberration upon  
said projection optical system, substantially in the same  
position as said mask is disposed; and

attaching, to a substrate stage which holds said substrate, a measuring unit including:  
a plurality of lens elements disposed on the image plane side of the projection optical system to  
5 converge the light beams through said projection optical system; a converging position detection unit disposed on the image plane of the lens elements to detect each of positions of the light beams converged by said lens array ; and a measuring  
10 device connected the converging position detection unit to measure the aberration of said projection optical system on the basis of the light beam positions detected by said converging position detection unit.

15

30. An aberration measuring method according to claim 29, further comprising:

removing said aberration measuring optical system after the light beam which measures the aberration have  
20 fallen upon said projection optical system; and

removing said measuring unit from said substrate stage after measuring the aberration of said projection optical system.

25

31. An exposure method which transfers onto a substrate an image of a predetermined circuit pattern by the use of a projection optical system, comprising:

measuring an aberration of said projection optical system by the use of said aberration measuring method claimed in claim 29 before transferring the circuit pattern onto said substrate.

5

32. A device manufacturing method, comprising:  
transferring onto a substrate an image of a predetermined circuit pattern by the use of a projection optical system,

10 measuring an aberration of said projection optical system by the use of said aberration measuring method claimed in claim 29 before transferring the circuit pattern onto said substrate.

15 33. An aberration measuring method according to claim 8, further comprising a step for correcting the measured aberration of said projection optical system.

20 34. A device manufacturing method according to claim 19, further comprising a step for correcting the aberration of said projection optical system on the basis of a measured result.

25 35. An aberration measuring apparatus which measures an aberration of a projection optical system which transfers onto a substrate an image of a pattern formed on a mask, comprising:



a measuring unit detachably provided on an exposure apparatus including a mask stage which holds said mask, said projection optical system, and a substrate stage which holds said substrate,

5            wherein said measuring unit includes:

a plurality of lens elements, two-dimensionally disposed, disposed on the image plane side of the projection optical system to converge the light beams through said projection optical system;

10           a converging position detection unit disposed on the image plane of the lens elements to detect each of positions of the light beams converged by said plurality of lens elements; and

15           an output unit which outputs a result of the detection by said converging position detection unit to a correcting mechanism for correcting the aberration of said projection optical system.

ABSTRACT OF THE DISCLOSURE

An aberration measuring apparatus has a converging lens L disposed on the light path of light beam to converge light beam traveling through a measurement target optical system PL on a predetermined surface IP, an aperture stop AP disposed on the light path of light beam to transmit a part of the light beams, a converging position detection unit DET disposed on the predetermined surface to detect a positional deviation of a converging position P of a part of the light beams traveling through the aperture stop on the predetermined surface IP, a moving unit M connected the aperture stop to move the aperture stop within the light beam, and an arithmetic processing unit connected the converging position detection unit to calculate an aberration of the measurement target optical system PL on the basis of an output signal from the converging position detection unit DET.

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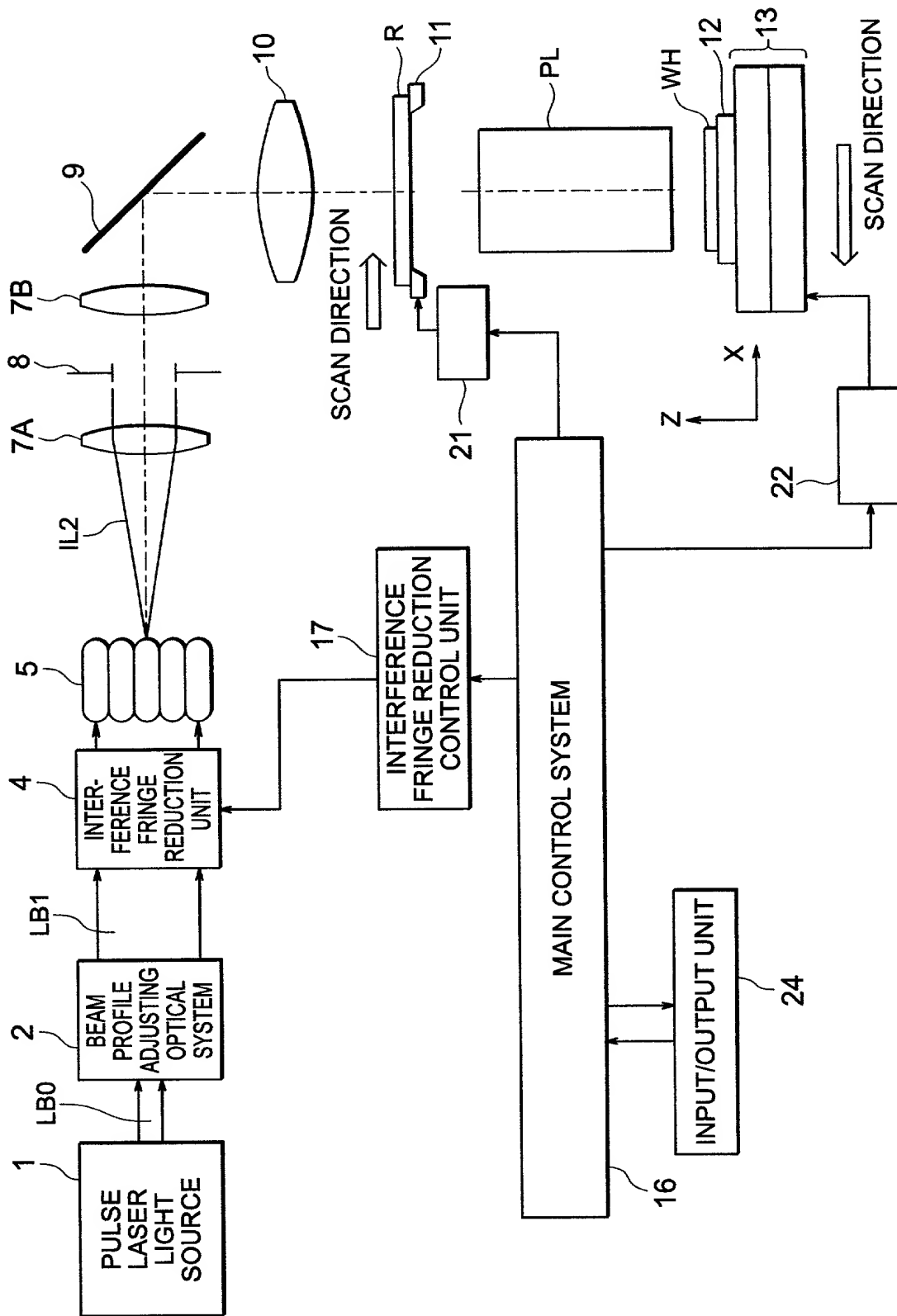


FIG. 2

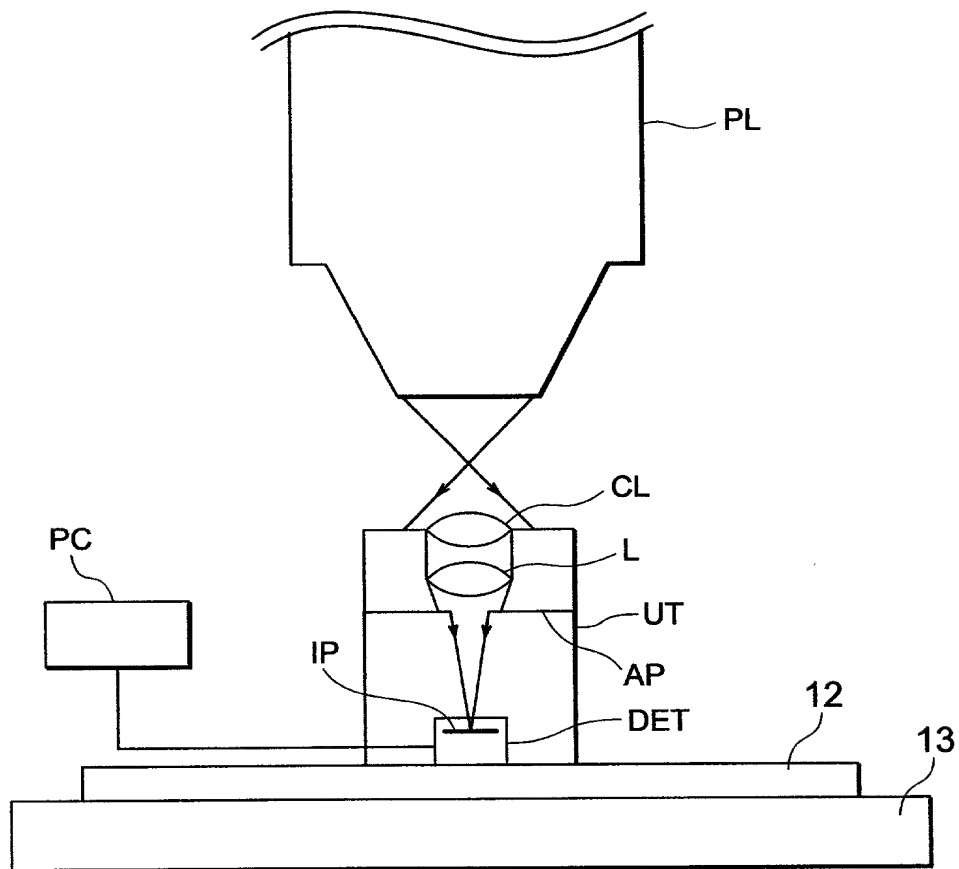


FIG. 3

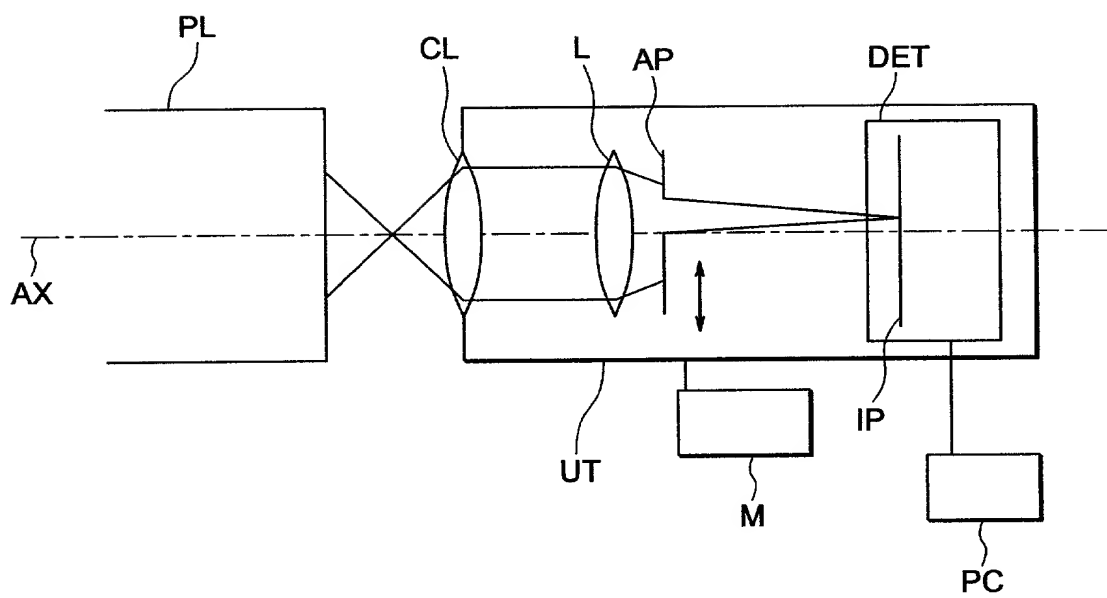


FIG. 4A

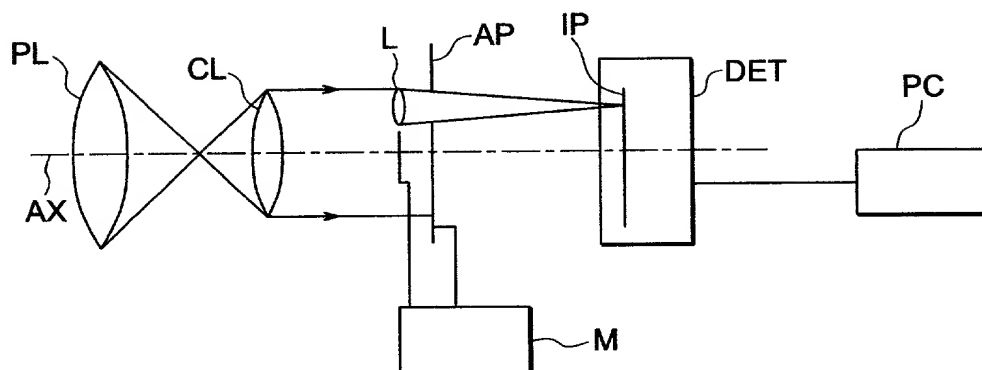


FIG. 4B

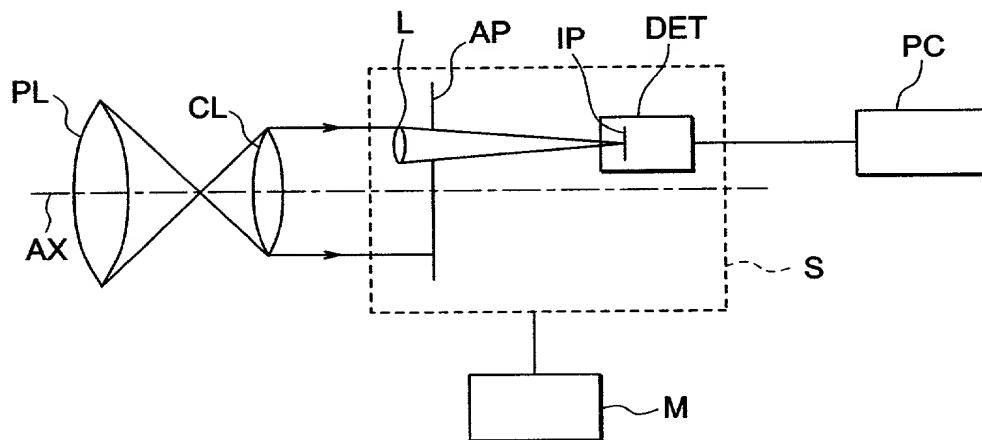


FIG. 5A

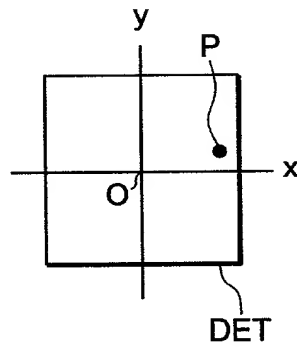


FIG. 5B

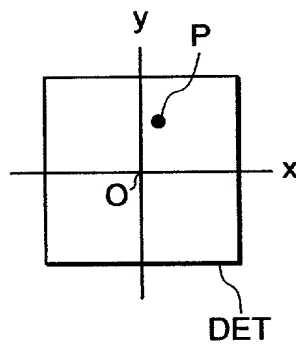


FIG. 5C

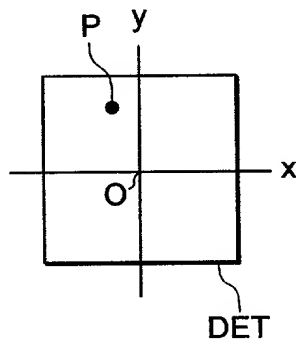
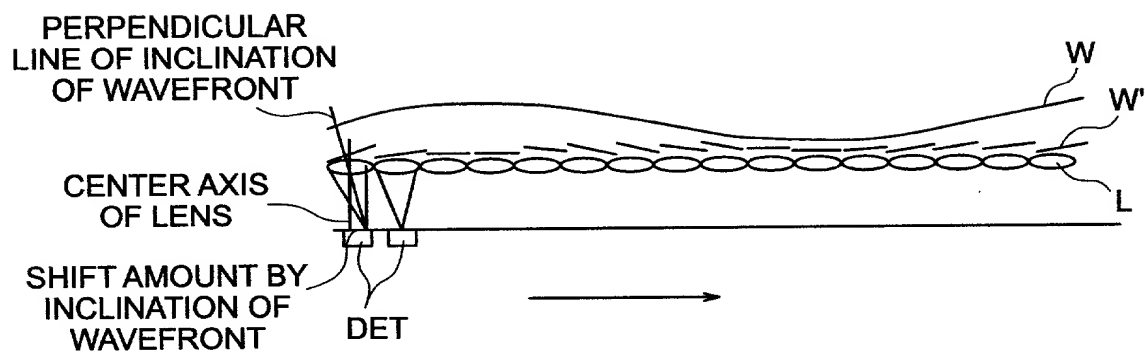


FIG. 6





# FIG. 7

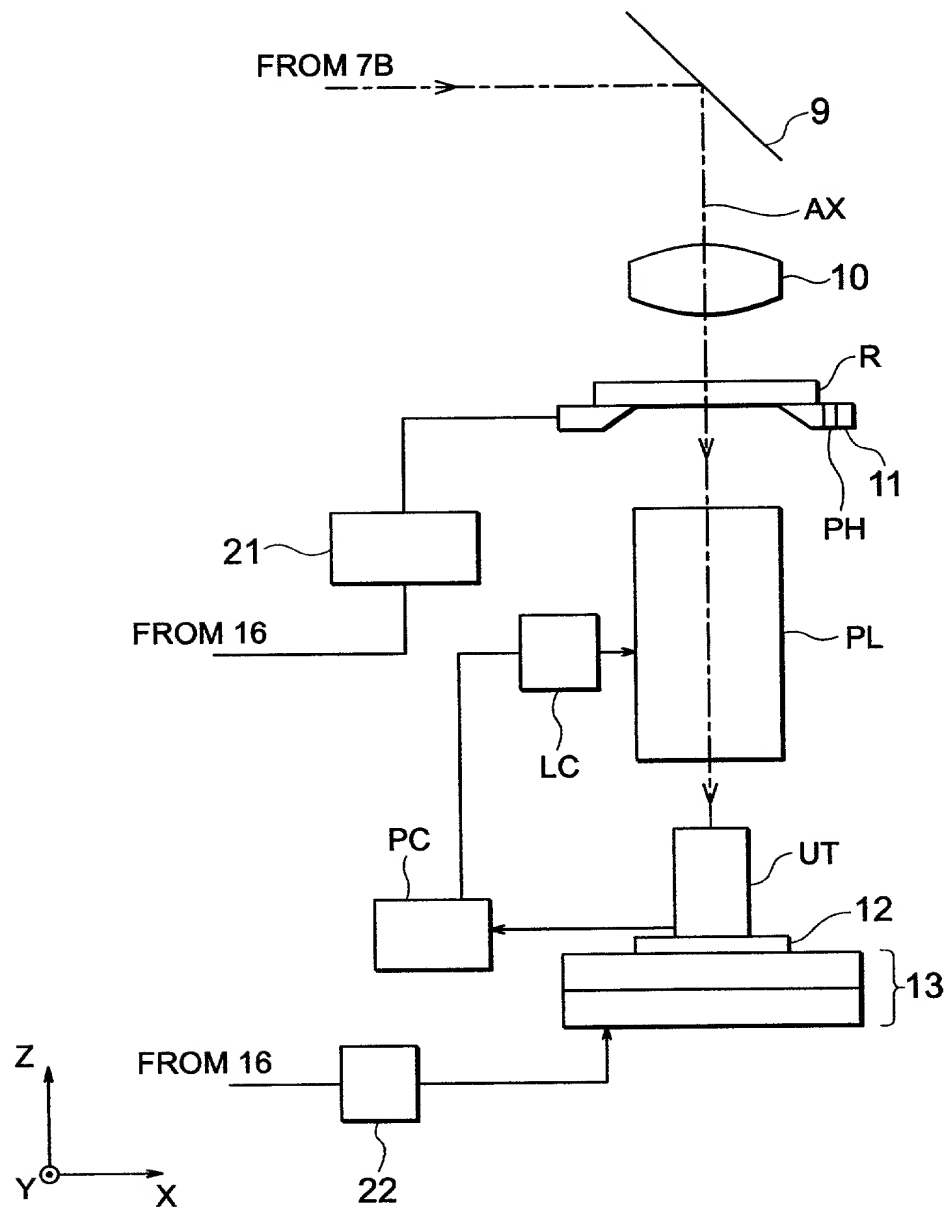


FIG. 8

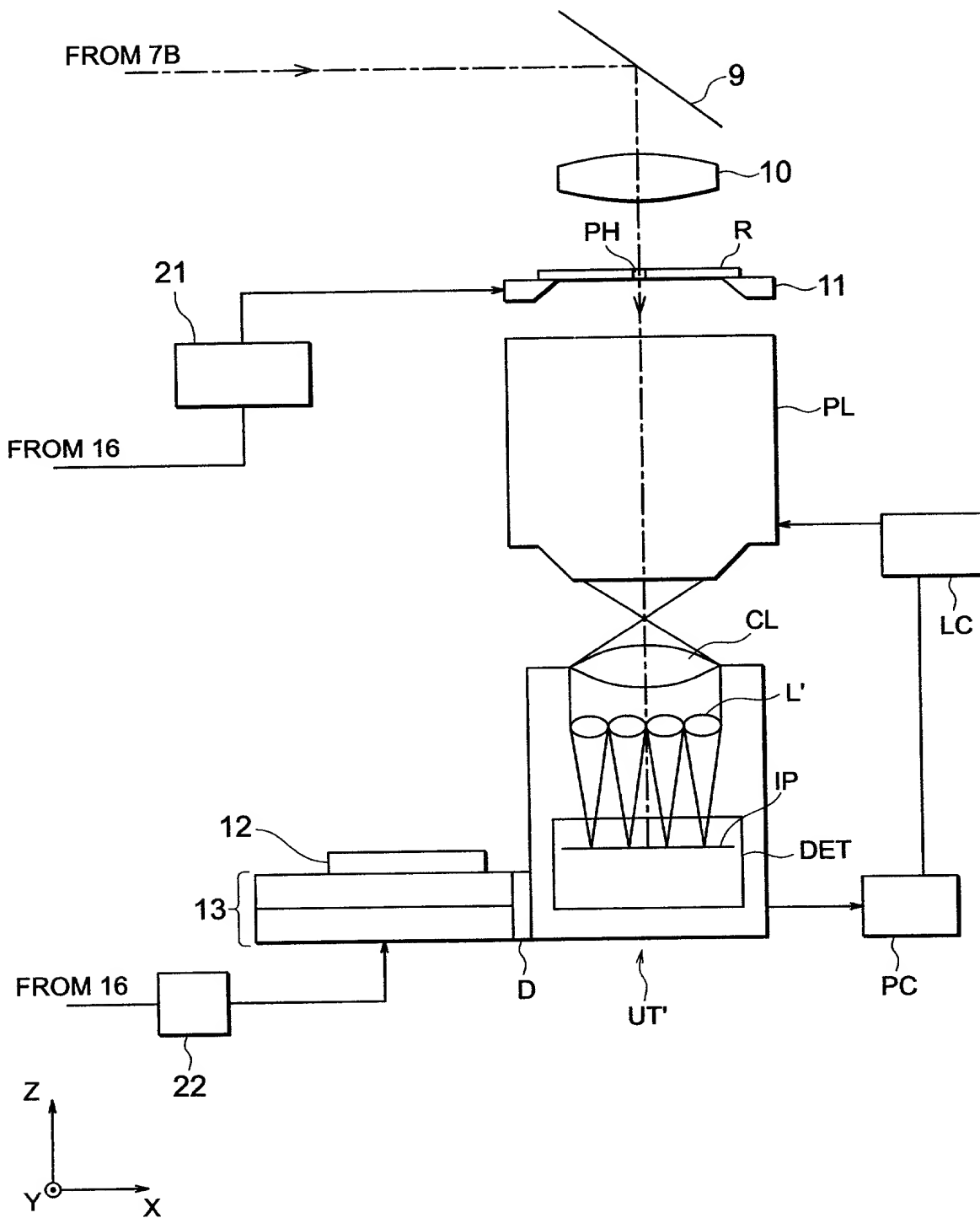
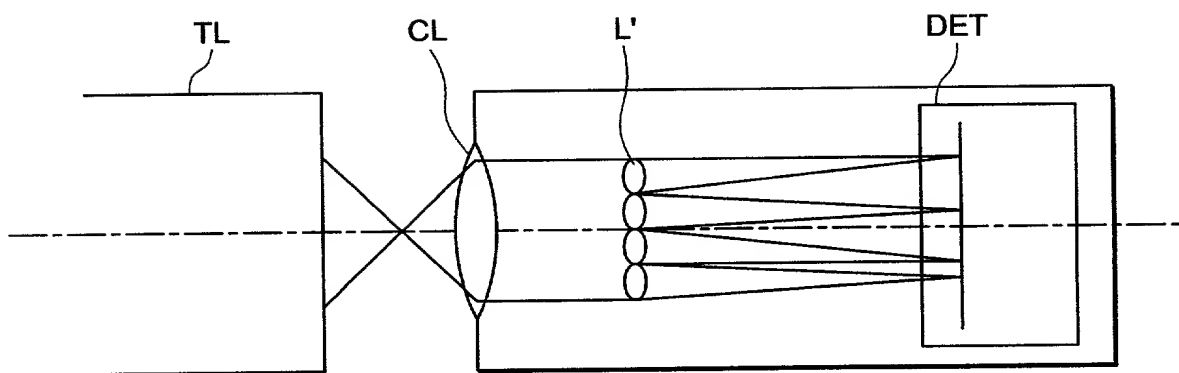


FIG. 9



# DECLARATION AND POWER OF ATTORNEY

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled ABERRATION MEASURING APPARATUS, ABERRATION MEASURING METHOD, PROJECTION EXPOSURE APPARATUS HAVING THE SAME MEASURING APPARATUS, DEVICE, the specification of which MANUFACTURING METHOD USING THE SAME MEASURING METHOD, AND EXPOSURE METHOD  
☒ is attached hereto.

☐ was filed on \_\_\_\_\_, as United States Application No. \_\_\_\_\_ or PCT International Application No. \_\_\_\_\_, and was amended on \_\_\_\_\_.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 (a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Application No.	Country	Filing Date	Priority Claimed	
			Yes	No
10-153915	JAPAN	May 19, 1998	<input checked="" type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below:

Application No.	Filing Date

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Application No.	Filing Date
PCT International Application No. PCT/JP99/02608, and was amended on April 24, 2000	International Filing Date May 19, 1999

I hereby appoint Nelson H. Shapiro, Reg. No. 17,095, Mitchell W. Shapiro, Reg. No. 31,568, James T. Wilson, Reg. No. 41,439, and the other practitioners associated with the Customer Number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith, and direct that all correspondence be addressed to that Customer Number:

Customer Number 20,230.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

- (1) Full name of sole or first inventor: Hitoshi TAKEUCHI  
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 Citizenship: JAPAN Residence: Fujisawa-shi, Kanagawa-ken, JAPAN  
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- (2) Full name of second joint inventor, if any: \_\_\_\_\_  
 Date: \_\_\_\_\_ Signature: \_\_\_\_\_  
 Citizenship: \_\_\_\_\_ Residence: \_\_\_\_\_  
 Post Office Address: \_\_\_\_\_